

Catalytic Converters for Exhaust Emission Control of Commercial Equipment Powered by Internal Combustion Engines*

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The development of PTX, monolithic catalytic exhaust purifiers, is outlined, and their first use for exhaust emissions control of commercial equipment is described. The main use of PTX converters is on forklift trucks. The purification achievable with PTX-equipped fork-lift trucks under various operational conditions is discussed, and examples from the field are given. During more than ten years of operation, no adverse health effects have been reported, and PTX-equipped internal combustion engines appear safe for use in confined areas.

Introduction

After World War II the necessity to protect the environment became more and more evident. At that time Engelhard began efforts to utilize catalytic processing, primarily catalytic oxidation, for the abatement of industrial and domestic air pollution. Among these programs, the development of systems to catalytically purify the exhaust of internal combustion engines had a high priority.

The concept of catalytic exhaust detoxification was not new; as early as in 1909, for instance, the use of finely divided platinum catalyst on a carrier and of secondary air injection into the exhaust had been proposed for this purpose (1), and several similar systems have been described in the years thereafter. However, only about 25 years

ago had catalytic science sufficiently advanced that viable solutions appeared feasible.

In the Engelhard development, particulate type catalysts were initially investigated. When monolithic ceramic carrier structures of suitable properties became available, Engelhard pioneered their use for exhaust emission control catalysts. This development led to the commercial introduction more than 10 yr ago of the PTX purifiers to control the exhaust of commercial equipment operated with engines using unleaded gasoline, diesel fuel, or LPG, allowing the safe use of such equipment in enclosed spaces.

PTX purifiers are used on fork lifts, trucks, floor sweepers, underground locomotives, stationary or portable engines, etc. They have been certified by the State of California Air Resources Board 69/22 for use on LPG fueled fork lift trucks used inside buildings. Furthermore, PTX diesel catalytic purifiers are permitted as part of the exhaust system on the U.S. Bureau of Mines Schedule 24 approved diesel units.

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Outline of History of the Development of the use of Monolithic Ceramic Structures for Exhaust Purification

The use of a unitary catalyst bed is particularly attractive for engine exhaust treatment. Among other advantages, there are no bed orientation problems, and in the case of straight-through channels, the possibility of plugging by particulate matter is minimized. One of the earliest suggestions of some kind of unitary type bed was made by Finn, who obtained a patent on a supported Ni-Cr-Co exhaust catalyst which could be molded into the form of tubes (2). Later on, Houdry described exhaust catalysts consisting of porcelain, such as perforated discs, as support for an alumina or other oxide film which, in turn, was promoted with precious or nonprecious metals (3,4). These structures suffered from both insufficient active- and insufficient superficial area and were lacking stability required for engine use. Metallic structures, such as folded woven metallic fabrics, which had been promoted with platinum metals have also been proposed for exhaust purification (5,6). However, experience has shown that metallic carrier structures are not suited for this service.

In the late fifties and early sixties, Engelhard developed high-activity, high-area unitary catalyst structures which have been described in a patent (7). Although the performance of these catalysts was considerably improved, they were fragile and subject to attrition. Therefore, in the early sixties when sufficiently stable unitary ceramic structures became commercially available by the Minnesota Mining and Manufacturing Company (8), Engelhard abandoned its own development on ceramic monoliths in favor of these materials. C. D. Keith and co-workers at Engelhard (9,10) produced the type of catalyst consisting of ceramic honeycomb structures coated with an active refractory oxide film and promoted with platinum metals which became the standard for the commercial PTX catalyst in 1963 as well as

for today's monolithic exhaust catalyst for passenger cars.

It is interesting to note that in the period of between about 1960 and 1970 various kinds of monolithic structures were also described—albeit not necessarily as catalyst or auto-exhaust catalyst support—by other organizations such as Corning (11,12), DuPont (13-15), General Motors (16), General Electric (17,18), and also in Germany (19). Minnesota Mining and Manufacturing Company also disclosed specific developments to utilize ceramic honeycomb structures for exhaust treatment (20-22).

The ceramic honeycombs produced by Minnesota Mining and Manufacturing Company, being the first commercially available to Engelhard for developing engine exhaust catalysts, have been used as support for the PTX purifiers on commercial equipment which are the subject of this paper.

Based on extensive engine and vehicle testing, PTX evolved. In 1965 conditions were not appropriate for use on passenger vehicles, however, for use with commercial equipment, such as fork lift trucks, employing unleaded fuels the technology of catalytic exhaust purification was firmly developed.

PTX: Exhaust Purifiers for Commercial Equipment

PTX systems are used for applications such as floor sweepers and scrubbers, mining equipment, construction equipment, generators, compressors, pumps, welders, tractors, snowmobiles, ice skating rink scrapers and edgers. However, the largest use is with fork-lift trucks, where PTX systems are used throughout the United States and in 25 foreign countries.

In a typical fork-lift truck installation, the PTX purifiers takes the place of the muffler. Raw exhaust gas from the engine passes first through a venturi which aspirates filtered air into the exhaust. Subsequently the air-exhaust mixture is reacted over the PTX catalyst. The heat generated by combustion of residual hydrocarbons and of carbon monoxide is sensed by a thermocouple in-

stalled in the outlet of the catalyst chamber. The signal of the thermocouple is transmitted to a dual-scale pyrometer usually mounted on the dashboard of the operator's cab. The output signal indicates that the catalyst is at the temperature required for proper activity and at the same time also that the engine operates efficiently. Continuous monitoring, therefore, ensures that the engine is kept in tune, optimizing fuel efficiency and engine life. The details of PTX systems have been described by Jagel and Lehmann (23).

About 75% of the 600,000 fork-lift trucks used in the United States are powered with internal combustion engines. Half the trucks operate on LP gas, 45% on gasoline, and 5% have diesel engines. Sulfur levels of diesel fuel No. 2 are normally 0.15–0.3% by weight, of gasoline about 0.05% by weight. By comparison the sulfur content of LP gas is quite low.

A popular size fork-lift truck has a capacity of 3,000 lb. A typical engine—operated either with LP gas or with gasoline—is a 4-cylinder, 4-stroke engine, having a dis-

placement of 162 in³, a compression ratio of 7.4, and developing 62 brake horsepower at 2700 rpm and a maximum torque of 136 ft-lb. at 1800 rpm. The fuel consumption at rated load would amount to about 5 gal. gasoline/phr, or 31 lb of LP gas/phr.

The temperatures of the exhaust of fork lift trucks ahead of the catalyst are typically in the range between 500°F and somewhat above 1000°F. After the combustion reactions in the PTX converter, the measured effluent temperatures lie usually between 800 and 1300°F.

Laboratory data obtained by Jagel and Lehmann (23) on a fork-lift truck equipped with a 155 CID 4-cylinder engine tested in the California 4-modes cycle using LP gas as fuel are shown in Tables 1–3. With catalytic purification, the weighted total emissions which include the cold start emissions were 99 ppm CO and 88 ppm residual hydrocarbons, whereas without a purifier the corresponding values were 10,000 ppm and 435 ppm (Table 2). After 25 sec of operation, carbon monoxide conversion was always over 97%.

Table 1. California cycle test of PTX purifier: raw data (lift truck #26, 4 cyl., 155 CID engine, LPG fuel).^a

Cycle	Mode	Without PTX purifier ^b			With PTX purifier ^b		
		HC, ppm	CO, %	CO ₂ , %	HC, ppm	CO, %	CO ₂ , %
1	Idle	480	1.8	9.8	220	0.3	7.1
	Accel	860	1.1	11.4	310	0.053	6.3
	Cruise	470	0.9	12.8	140	0.027	6.6
	Decel	250	0.5	7.6	60	0.004	4.8
2	Idle	500	1.7	10.2	100	0.01	7.1
	Accel	510	1.3	11.4	140	0.008	6.7
	Cruise	410	1.1	12.8	80	0.006	6.8
	Decel	320	1.5	6.5	40	0.005	4.6
3	Idle	480	1.9	10.2	65	0.008	7.1
	Accel	525	1.2	11.4	105	0.019	7.0
	Cruise	410	0.9	12.8	65	0.006	7.0
	Decel	380	0.6	6.1	45	0.003	4.6
4	Idle	470	1.9	10.2	60	0.006	7.1
	Accel	530	0.6	11.4	140	0.007	5.4
	Cruise	400	1.1	12.8	55	0.006	6.8
	Decel	370	0.4	5.8	105	0.003	4.2
5	Idle	480	1.9	10.2	65	0.005	7.2
	Accel	490	0.5	11.4	85	0.013	6.5
	Cruise	370	0.9	12.8	60	0.005	6.8
	Decel	270	0.5	8.0	40	0.003	4.6

^a California operating cycle (4 modes). Five cycles are run, starting with a cold start. The overall emissions are calculated as a weighted average of cycles 1, 2, 4, and 5. (Table 2). Details of the cycle are given in Table 3.

^b Note the substantial reduction of carbon monoxide after the first cold start cycle. The PTX purifier reduced carbon monoxide in the first minute from an initial 1.80% to 0.004%.

Table 2. California cycle test of PTX purifier on typical fork-lift truck: Weighted total emissions.

Cycle	With PTX purifier		Without PTX purifier	
	CO, ppm	HC, ppm	CO, ppm	HC, ppm
1	270	166	9,500	528
2	65	90	11,600	429
4	60	69	10,500	429
5	62	64	8,900	394
Weighted Avg.	99	88	10,000	435

Table 3. California cycle modes.

	RPM	Intake vacuum, in. Hg	Time in mode, sec	Cumul. time, sec	% time	Weighting factor
Idle			20	20	34	0.057
Acceleration		6-8	5	25	8	0.155
Load	2,000	13	30	55	50	0.774
Deceleration			5	60	8	0.014

The actual service conditions of fork-lift trucks are different from the engine cycles of the California mode testing. However, conversions of carbon monoxide and of hydrocarbons we measured on a PTX equipped fork lift truck under a variety of service conditions, shown in Table 4, are in line with the results given in Tables 1-3. Conversion of carbon monoxide was virtually complete in all operational modes, that of hydrocarbons varied from somewhat below 50% to over 90%. It should be noted that low hydrocarbon conversions were associated with low hydrocarbon emissions in the exhaust (tests 4,6: 80-110 ppm) and that part of hydrocarbon emissions consist of methane which is difficult to oxidize but innocuous. However when hydrocarbon emissions became high upon disconnecting of a spark plug (test 10) hydrocarbon conversion rose to 90% and above. Results such as shown in Tables 1-4 are being matched by field experiences. This is illustrated by the following examples.

PTX purifiers have been installed by Hunt Wesson Foods on fork-lift trucks which are operated with LPG in warehouses where air circulation may be poor in working areas, especially inside dock areas or rail cars (24).

Trucks fitted with PTX units exhibited the following CO emissions listed in Table 5.

At Hunt Wesson Foods the air in the warehouses is regularly tested for CO; in the event the OSHA threshold of 50 ppm should be exceeded, the trucks involved are checked and necessary corrections are made. Lift trucks with PTX purifiers can now be used in shortening packing areas which had previously not been feasible because of the sensitivity of shortening to odors.

Maritime companies are using LPG-fueled fork-lift trucks for materials handling in waterfront warehouses, at docks and in ship holds. The PTX purifiers permits the use of these trucks in confined areas meeting Coast Guard regulations for carbon monoxide emissions (25).

At the terminal of the Luckenbach Steamship Company in Philadelphia it was reported (25), for instance, that during more than five years' experience that PTX purifiers were significant in preventing illnesses, accidents, and damages and afforded increased productivity in the operation of fork-lift trucks in ships' holds.

A case of gasoline fueled fork lift trucks fitted with PTX purifiers is at Rohm and Haas. This company is using fork-lift trucks

Table 4. Test of PTX purifier on Allis Chalmers Model ACP 70 fork-lift truck *

No.	Type of operation	Mixture	Ignition	Rpm	Emissions before PTX		Conversion after PTX, %	
					Hydrocarbons, ppm	CO, ppm	Hydrocarbon	CO
1	Truck moving, no load	Correct	Correct	800	216	29,900	92.6	99.94
				1,200	210	16,500	91.7	99.88
				1,600	178	25,125	93.3	99.88
2	Truck moving, load on	Correct	Correct	800	176	16,000	83.3	99.69
				1,200	169	15,500	88.1	98.84
				1,600	260	25,250	92.6	99.85
3	Truck moving, load on	Rich	Correct	800	127.5	11,900	74.1	99.56
				1,200	85	22,000	61.6	99.88
				1,600	125	16,500	80.8	99.62
4	Truck moving, load on	Lean	Correct	800	109	10,550	61.0	99.94
				1,200	80	17,250	47.5	99.94
				1,600	105	10,650	62.9	99.80
5	Truck stationary, load on	Correct	Correct	800	167.5	22,500	72.1	99.76
				1,200	210.5	23,250	79.8	99.70
				1,500	232.5	31,850	90.4	99.65
6	Truck stationary, load on	Rich	Correct	800	127.5	28,500	69.8	99.94
				1,200	107.5	14,000	46.2	99.98
				1,600	135	14,750	88.0	99.87
7	Truck stationary, load on	Lean	Correct	800	122.5	10,000	70.3	99.98
				1,200	117.5	15,000	68.1	99.83
				1,600	100	14,000	79.1	99.82
8	Truck stationary, load on	Correct	Retarded	800	95	2,200	80	99.65
				1,200	117.5	19,500	80.9	99.67
				1,800	170	27,000	90.9	99.63
9	Truck stationary, load on	Correct	Advanced	800	165	5,650	81.7	99.91
				1,200	189	14,500	81.5	99.74
				1,500	209.5	27,125	90.3	99.67
10	Truck stationary, load on	Correct	One spark plug disconnected	800	4,100	10,000	89	99
				1,200	4,950	22,000	97.2	99.52
				1,500	5,300	21,500	96.7	99.37

* Weight, 7000 lb; 6 cylinder, 230 CID, 4-cycle engine HP 77; rated RPM, 1800; fuel, LPG; load on forks, 6000 lbs.

16 hr/day for moving a variety of chemical products in and out of its distribution center in Philadelphia (26). Trucks have been operated at full efficiency for one year without need for rebuilding or replacement.

Another case of the use of PTX purifiers on gasoline fueled engines is an application of the New York City Transit System which employs portable pumps to pump water from subway tunnels after heavy rains or due to other causes. The pumps are operated for periods of 1-4 hr at a time. It is our understanding that problems with CO emissions and with irritating odors in these very con-

fined spaces have been eliminated upon installation of PTX purifiers.

An application of PTX purifiers on diesel-powered fork lift trucks is at the Oswego, N.Y. facility of Alcan Aluminum (27). The PTX catalysts oxidize CO, hydrocarbons, and

Table 5.

Truck No.	CO, ppm
89	10
91	5
92	20

exhaust odors; catalysts last for several thousands of hours.

Conclusions

An estimate of the total operational time during the last ten years of use of commercial PTX purifiers is about 1.2×10^8 hr. Some converters have exceeded 10,000 hr of operational life. We are not aware of any instance in which a health problem has been reported connected with PTX-equipped internal combustion engines. In the contrary, the cited evidence shows that health benefits are derived from the use of PTX purifiers. According to our own and according to all commercial experiences which have come to our attention, we see no cause to doubt the safety of the operation of PTX purifiers on mobile and stationary internal combustion engines.

The question of possible adverse effects of sulfate emissions has been raised only relatively recently, and no systematic study of any such effects with commercial equipment appears to have been completed. However, during the years of use of PTX purifiers in confined spaces no irritation or other health problems, and this would include sulfate effects, have been reported to us. Particularly significant in this respect is the widespread use of PTX purifiers on diesel locomotives in underground mines, in spite of relatively high sulfur content of diesel fuel.

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